Correlations of Electrons from Heavy Flavor Decay with Hadrons in Au+Au and p+p Collisions

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Abstract. Measurements of electrons from the decay of open-heavy flavor mesons have shown that the yields are suppressed in Au+Au collisions compared to expectations from binary-scaled p+p collisions. These measurements indicate that charm and bottom quarks interact with the hot-dense matter produced in heavy-ion collisions much more than expected. Here we extend these studies to two-particle correlations where one particle is an electron from the decay of a heavy-flavor meson and the other is a charged hadron from either the decay of the heavy meson or from jet fragmentation. These measurements provide more detailed information about the interactions between heavy quarks and the matter, such as whether the modifcation of the away-side-jet shape seen in hadron-hadron correlations is present when the trigger particle is from heavy-meson decay and whether the overall level of away-side-jet suppression is consistent. We statistically subtract correlations of electrons arising from background sources from the inclusive electron-hadron correlations and obtain two-particle azimuthal correlations at $\sqrt{s_{NN}}$ =200 GeV between electrons from heavy-flavor decay with charged hadrons in p+p and also first results in Au+Au collisions. We find the away-side-jet shape and yield to be modified in Au+Au collisions compared to p+p collisions.

1. Introduction

One of the main goals of heavy ion physics is to understand the interactions between the produced matter (commonly understood as a strongly couple quark gluon plasma, sQGP) and fast partons. Measurements of the nuclear modification factor, R_{AA}, of π^0s [1] show a large suppression which is understood as resulting from parton-matter interactions throughout the time evolution of the matter. Further studies, in which a trigger π^0 is correlated with other hadrons in the event have shown a strong suppression of back-to-back jet-like correlations [2].

These results are qualitatively as expected from energy-loss models. However, heavy charm and bottom quarks have the ability, via their large mass, to provide additional constraints on the mechanisms by which the partons interact with the matter. Notably, heavy guarks are expected to suffer less energy loss via gluon radiation in the matter because of the dead cone effect [3].

Heavy quarks in heavy ion collisions have largely been studied via single electrons which come from the decays of D and B mesons which carry the original heavy quark. The R_{AA} of these electrons has been shown to be significantly below 1 and comparable to that of π^0s [4]. Measurements of single electrons are sensitive to both charm and bottom quarks, with a mixture that depends on the electron p_T [5, 6].

In order to further study these effects we have performed two-particle correlations of electrons from heavy flavor decay with other hadrons, in the same manner as has been done for π^0s. This

can provide a more detailed view of the interactions between heavy quarks and the sQGP. However, there are additional complications when considering heavy quarks, thus baseline measurements in p+p collisions are vital. The results shown here have been published as Ref. [7].

2. Method

Experimentally, separating the correlations of heavy flavor electrons from those of non-heavy flavor electrons (such as those from photon conversions and Dalitz decays) is necessary. The procedure used is outlined in Ref. [7]. In general, a precise knowledge of the relative yields of heavy flavor and non-heavy flavor sources is needed. With that and a measurement of the correlations of non-heavy flavor electrons it is possible to statistically subtract the non-heavy flavor correlations from the total electron correlations (which include both the heavy flavor and non-heavy flavor correlations). This is analogous to the procedure used to separate direct photon triggered correlations from those triggered by decay photons in Ref. [8].

3. Results

The near side yields conditional yields are shown in Figure 1 and are consistent with those observed in p+p collisions. This is quantified by the ratio of the conditional yield in Au+Au collisions divided by the conditional yield in p+p collisions, I_{AA}, shown in Figure 2. This is a good cross check because those yields are expected to be dominated by the decay of the heavy meson (D or B) which occurs far from the matter and thus should be unaffected by its presence. It is perfectly possible for the matter to enhance the near side correlations through some process, it is difficult to imagine a scenario where the yields are suppressed.

Figure 3 shows the away side conditional yields for both Au+Au and p+p collisions as a function of the associated hadron p_T and for two different trigger p_T selections and two ranges for the away side azimuthal angle integration. The correspondig I_{AA} values are shown in Figure 4. In general at low $p_{T,hadron}$ the yields are enhanced in Au+Au collisions compared to p+p and at higher $p_{T,hadron}$ the yields are suppressed. Qualitatively, this is consistent to trends found in hadron-hadron correlations (see e.g. Ref. [9]). In order to make a more quantiative comparison we take into account that the electron p_T is not the relevant p_T with which to compare to the hadron-hadron I_{AA} values. We use PYTHIA [10] simulations of the parent B and D (weighted according to Fixed Order Next to Leading Log (FONLL) [11] calculations of the mixture of charm and bottom) p_Ts which give rise to the electrons in our trigger p_T selections (see Table 1) and compare to hadron-hadron I_{AA} at comparable p_T values. This comparison is shown in Figure 4; good agreement is seen between the electron-hadron and hadron-hadron I_{AA} values. It might also be reasonable to compare the hadron-hadron and electron-hadron I_{AA} at similar parton p_T, accounting for the different fragmentation of heavy and light quarks. However, given the current uncertainties, the comparison at similar meson p_T seems reasonable and gives good agreement.

$p_{T,e}$ (GeV/c)	$\langle p_T \rangle_D$ (GeV/c)	$\langle p_T \rangle_B$ (GeV/c)	$\frac{b \to e}{(c \to e + b \to e)}$	$\langle p_T \rangle_{meson}$ (GeV/c)
1.5-2.0	3.4	4.4	0.15	3.6
2.0-3.0	4.1	4.7	0.26	4.3
3.0-4.0	5.6	5.6	0.42	5.6

Table 1. Mean transverse momentum of the parent D and B mesons contributing to the heavy-flavor electron p_T bins used here. They are combined according to the fraction of heavy-flavor electrons from b quarks, $\frac{b \to e}{(c \to e + b \to e)}$ according to the FONLL calculations [11] (as shown in Ref. [5]) to determine the mean heavy meson transverse momentum.

For many years, a strongly modified away side shape has been seen in hadron-hadron

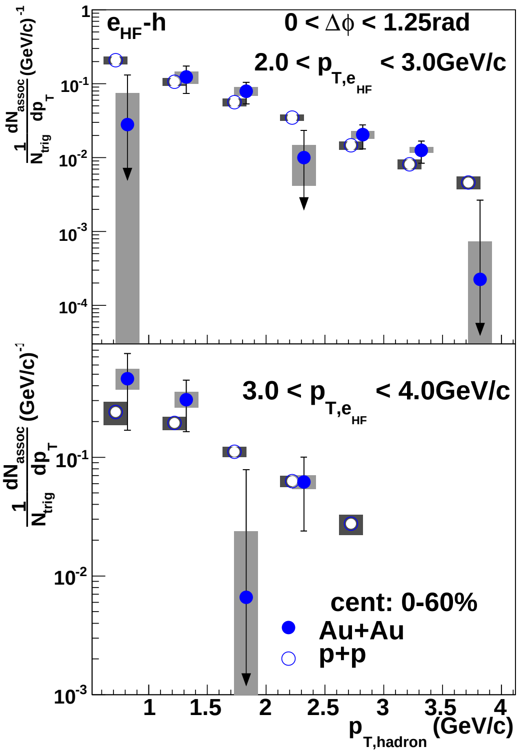

Figure 1. (color online) Near-side ($0< \Delta\phi <1.25$ rad) integrated yield for Au+Au (solid circles) and p+p collisions (open circles) for $2.0< p_{T,e} <3.0$ GeV/c (top panel) and $3.0< p_{T,e} <4.0$ GeV/c (bottom panel) as a function of the associated hadron p_T. The overall normalization uncertainty of 9.4% in Au+Au and 7.9% in p+p is not shown. Points are slightly shifted horizontally for clarity. Figure is from Ref. [7].

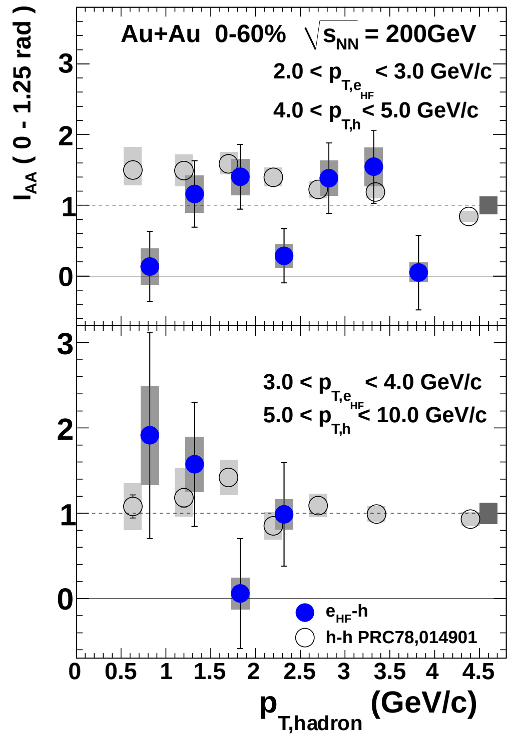

Figure 2. (color online) Near-side ($0< \Delta\phi <1.25$ rad) I_{AA} for $2.0< p_{T,e} <3.0$ GeV/c (top panel) and $3.0< p_{T,e} <4.0$ GeV/c (bottom panel) as a function of the associated hadron p_T for e_{HF} (solid points) and hadron (open points) triggers (from Ref. [9]). The gray band around unity shows the overall normalization uncertainty (12.4%), which moves all points together. Points are slightly shifted horizontally for clarity. Figure is from Ref. [7].

correlations [12]. This has been attributed to various sources, among the most prevelant being the remains of a Mach cone [13]. With that motivation in mind we analyzed the away side shape for electron-hadron correlations. Heavy quarks, especially bottom, at moderate p_T values travel at a velocity slower than the speed of light. Since the angle of the Mach cone opening depends on the velocity of the parton relative to the speed of sound, bottom quarks offer the opportunity to confirm a Mach cone by looking for a variation in the opening angle.

We measured the head-to-shoulder ratio, R_{HS}, which is the yield per radian measured into the head region, $2.51< \Delta\phi < \pi$ rad, divided by the same quantity in the shoulder region, $1.25< \Delta\phi <2.51$rad. The results for p+p and Au+Au collisions are shown in Figure 5. There is a significant increase in this ratio in Au+Au collisions compared to p+p collisions. No dependence on the associated particle p_T is observed.

Since the publication of these data [7], there is evidence that the modified away side structure is due to fluctuations in the initial state of the Au+Au collisions which are then transported to the final state hydrodynamically [14, 15, 16]. The modification of the away side correlations in

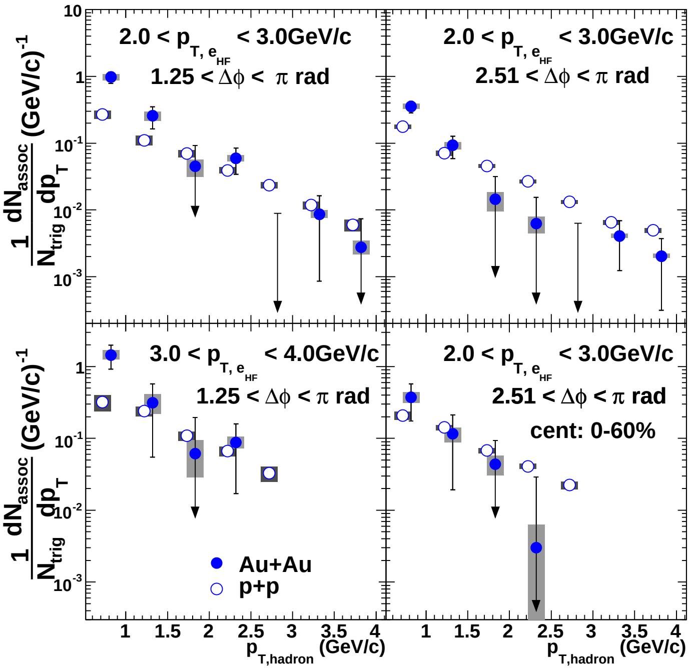

Figure 3. Away-side conditional yields for wide (left) and narrow (right) away-side $\Delta\phi$ integration ranges for Au+Au (solid points) and p+p (open points). Top panels show 2.0< $p_{T,e}$ <3.0 GeV/c and bottom panels shown 3.0< $p_{T,e}$ <4.0 GeV/c. Upper limits are for 90% confidence levels. The overall normalization uncertainty of 9.4% in Au+Au and 7.9% in p+p are not shown. Points are slightly shifted horizontally for clarity. Figure is from Ref. [7].

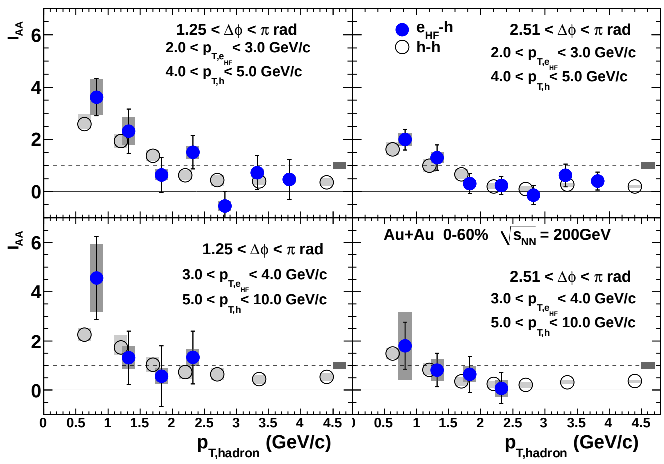

Figure 4. $I_{\rm AA}$ as determined from the away-side yields in Fig. 3. Two $\Delta\phi$ ranges are shown: 1.25< $\Delta\phi$ < π rad (left panels) and 2.51< $\Delta\phi$ < π rad (right panels). The gray band around unity shows the overall normalization uncertainty of 12.4%, which moves all points together. For comparison hadron-hadron $I_{\rm AA}$ values from Ref. [9] are also shown for trigger p_T selections where the parent heavy meson has similar p_T to the trigger light hadron (see Table 1). Points are slightly shifted horizontally for clarity. The solid horizontal line is at 0 and the dashed horizontal line is at 1. Figure is from Ref. [7].

electron-hadron correlations seen here is consistent with that understanding. In the trigger p_T selection used in Figure 5, previous measurements already show a large v_2 value [4]. Thus, it would be expected that higher order Fourier coefficients (e.g. v_3), by which these fluctuations have been measured, would also be seen for these electrons (such a measurement has not been done, but would be very interesting).

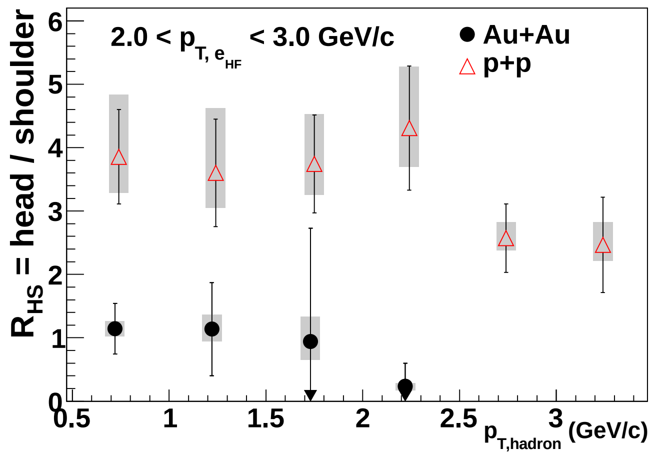

Figure 5. Ratio of the yield in the head region per radian to that in the shoulder region per radian for Au+Au (black) and p+p (red). Figure is from Ref. [7].

4. Conclusions

The mechanisms by which hard probes interact with the QGP are still not understood. Measurements involving heavy quarks have posed a particular problem to energy loss models based on radiative energy loss. However, there are many uncertainties in the theoretical calculations and the need for more and better measurements both at RHIC and the LHC. At PHENIX, the Silicon Vertex Detector was installed for the 2011 RHIC running period which will allow the separation of electrons from charm and bottom. This will be a major step forward to understand how the parton mass alters the effects of parton-matter interactions.

References

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